

Jatropha to Biofuel



- Crop grows on marginal land but needs ample water supply
- Optimum yield 5x more fuel / acre / yr than corn
- Production: a) variable, depending on soil quality, b) highly labor intensive, c) depends on plant life, d) multiple harvests per year
- Leaves & seeds highly toxic
- Requires tropical climate: suitable in climates of Myanmar, India, China, Philippines, etc.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE SEP 2010		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Jatropha to Biofuel				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Laboratory Washington, DC 20375				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADA560467. Indo-US Science and Technology Round Table Meeting (4th Annual) - Power Energy and Cognitive Science Held in Bangalore, India on September 21-23, 2010. U.S. Government or Federal Purpose Rights License					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 29	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Challenges for DoD Fuel from Algae

for 50% additive (2.4 B gal / yr)



- Need high solar flux, abundance of water, CO₂ and nutrients (N, P, etc.)

- Massive need for **wetlands and ponds**

2500 gallons “oil” / acre / year requires 1600 square miles



- Use of **coal fired power plants** to sustain production
233 coal power plants in south east US burn about 330 million tons of coal per year and produce about 860 million tons CO₂ per year
2500 gallons “oil” / acre / year requires 20 million tons CO₂ per year (high CO₂ transportation cost if not adjacent)
- Massive **water requirements**
2500 gallons “oil” / acre / year requires 1 trillion gallons of water per year (~ 1 / 120 of the volume of water in Lake Erie)
- 1 % S in coal will acidify the water to pH from ~ 5 to 3 (killing algae harvest)
- Costs of fuel could (**if the algae ponds and coal fired power plants are adjacent**) be as low as \$ 2- 3 / gallon, excluding capital investment and SO₂ removal

Challenges for Navy Jet Fuel from Camelina (Montana project, excluding land cost) for 50% additive (~ .3 B gal / yr)



- Relies on massive arable (non-food) land use.
- Camelina at <100 gallons per acre per year would require 3 million acres or 1 / 20 of all pasture land in Montana
- Fertilization ($\sim 100 \times 10^6$ pounds per year) at a cost of \$100 M / yr
- Requires planting & harvesting cost at \sim \$280 M / yr
- Processing costs to jet fuel \sim \$3 B / yr (\$ 10 / gal)
- Processing costs to bio diesel fuel \sim \$ 1 / gal
- Market demands dictate diesel and not just jet fuel production
- Crop rotation with dry land wheat is under study



Pasture Land: 53 % of MT

Crop Land: 19 % of MT

Camelina for Navy 50 % Jet Fuel: 4 % of MT

Cyanobacteria: an incredible group of microbes



- Ethanol production in US / yr is
~ 4 B gal; 3 % of fuel consumption
- ~ 2 / 3 gal of oil used to produce
1 gal of ethanol

- Capture CO₂ and photons through photosynthesis (similar to plants and algae)
- Grow in fresh or saline water
- Fix nitrogen from atmosphere (eliminate nutrient additives)
- Produce sugars and polysaccharides
- Can easily be genetically modified for efficient production of sucrose, glucose, etc.
- Allow products to be extracted without harming the cells
- Are estimated to be able to produce
> 700 gal of ethanol / acre / yr



Hydrogen: A Clean Energy Source

(From Oil To Hydrogen)



Massive R&D Challenges

Production	Cost-effective hydrogen generators
Distribution	Much lower cost; reliability
Fueling	Standard fueling station and dispensing systems
Storage	High density storage; ease of release
Conversion	Hydrogen to electricity (fuel cells)
Detection	Compact and accurate hydrogen sensors (Typical leakage 1-3%)



Hydrogen has high energy content, and is non-polluting. Why has it not been widely used as a fuel?

Energy content of various fuels, referenced to gasoline.

Fuel	Energy /mass / volume		Temp. Mass / volume	
Gasoline	1.0	1.0	25 C	1.0
Methanol	0.44	0.51	25 C	1.1
Ethanol	0.61	0.69	25 C	1.1
Liquid Hydrogen	2.60	0.27	-253 C	0.1
Hydrogen Gas (@3,000 psi)	2.60	0.06	25 C	0.02
Hydrogen Gas (@ 10,000 psi)	2.60	0.20	25 C	0.08
Lithium Ion Battery	0.019	0.035	25 C	2.03

Other properties:

- wide limits of flammability
- low spark ignition energy
- nearly invisible flame

Storage:

- high pressure, or cryogenics
(both have issues for the DoD,
particularly combat situations)

Distribution:

- pipelines cost ~ \$1M/mile
- would need to be newly laid

NOTE: Hydrogen has lowest heating value/ unit vol, w exception of Li battery.

Coffey et al, Defense Horizons, No. 36, 2003

Production



Steam reforming of methane



- To produce energy equivalent of oil consumed each year in the US, we would require 3×10^{14} gm of H_2 (300×10^6 tons); (from 6×10^{14} gms (3×10^{13} ft³) of CH_4 , 13.5×10^{14} gms of water with byproduct of 16.5×10^{14} gms of CO_2 (Current US use of CH_4 is 2.2×10^{13} ft³/yr)
- Burning CH_4 for equivalent energy, we need 25% less CH_4 and produce 25% less CO_2

Electrolysis: Use of electricity to produce H_2 from H_2O

- Need 3.9 kW hr of electrical energy to produce 1 m³ of H_2 with energy value of 3.2 kW hr (80% efficiency)
- 3.4×10^{12} m³ of H_2 needed to replace US oil needs, requires 13.2×10^{12} kW hr of electrical power (US annual electrical production is 3.7×10^{12} kW hr)*

Energy from the Ocean



Tidal Energy

Variations in sea levels (twice daily) due to the gravitational effects of the sun and the moon turn immersed turbines

Advantages:

- Large scale investment (100 MW+)
- Proven technology
- Protection from coastal flooding

Disadvantages:

- Specific sites (40 world wide)
- Intermittent operation (4 flows/day)
- High capital investment (\$3-10K/kW)
- Environmental issues
- Navigation limits

Wave Energy

Rise and fall of waves moves cylinder which drives electric generator

Advantages:

- Single buoy (50 kW)
- Existing technology (tested at New Jersey by OPT)
- No environmental impact

Disadvantages:

- Coastal navigation
- High sea states
- Fisheries
- Capital investment



Synthetic fuel from the Sea



Synthetic Fuel Production

Objective:

Feasibility of producing sea-based synthesized hydrocarbon fuels

Benefits:

Synthetic Fuels: a “Game Changing” Proposition

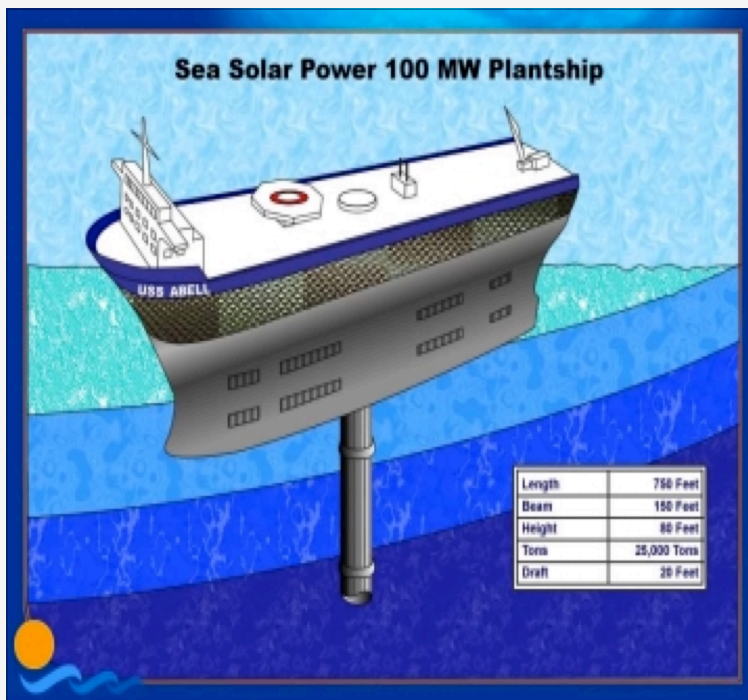
- Total independence from impending global oil crisis (price fluctuation, availability)
- Reduce vulnerabilities and storage
- Synthetic Jet fuels superior to petroleum based fuels (reduced engine maintenance and reduced aviation fuel exhaust)
- Assured source of jet fuel
- Zero net pollution to environment (CO₂ neutral)

Fuel Where and When You Need It



Ocean Thermal: a renewable energy source

- Oceans are the largest solar energy collector on earth
- Stored energy in the equatorial / tropical oceans equals ~ 300 times the world's energy consumption
- Energy conversion is 24 hours per day; not only when sun shines
- Energy extraction is environmentally neutral



Ocean Thermal Energy Conversion (OTEC)

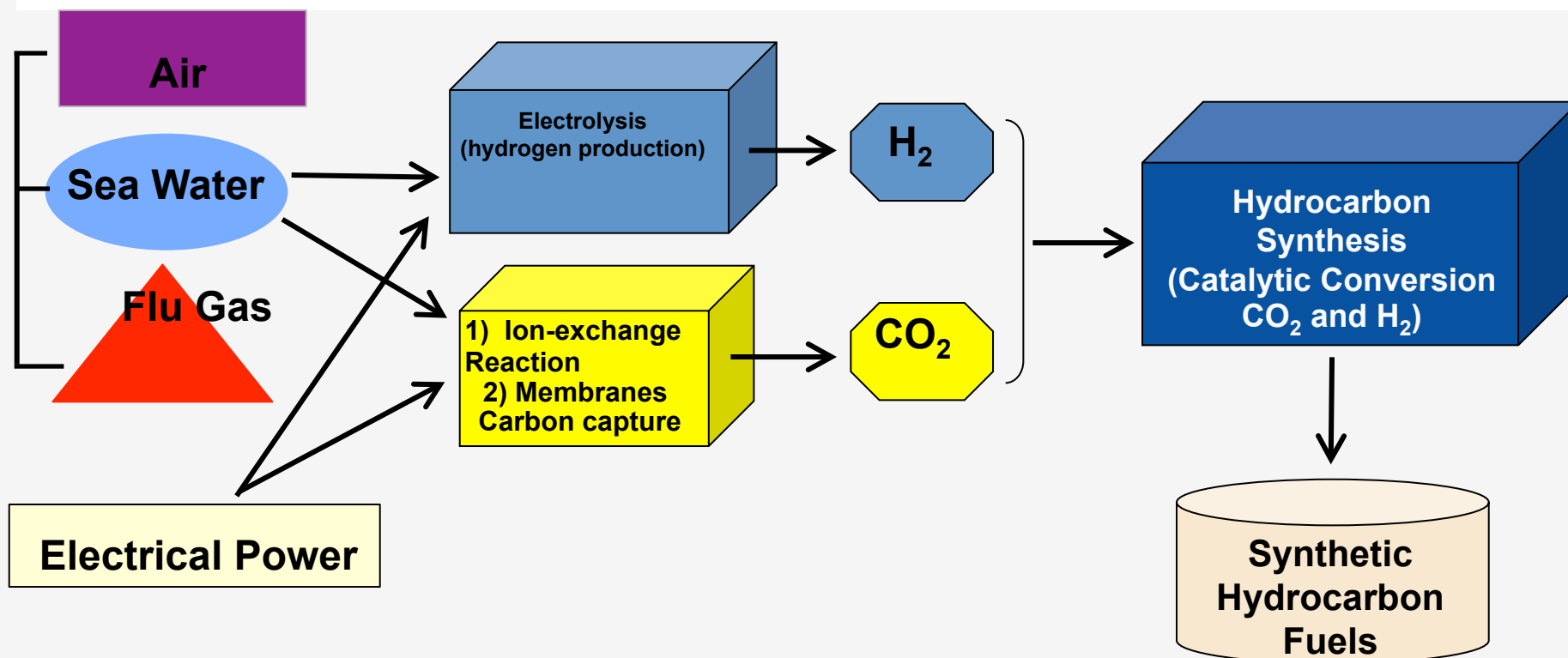


- Efficient method to convert solar energy stored in tropical ocean waters to electricity
- 80°F surface water boils working fluid (propylene) under pressure; expanded vapor to turbines to produce electricity
- < 40°F cold water pumped from ~ 3000 ft to condense vapor back to liquid
- 100 MW plant needs 32 M gal water / day
- Power used to produce H₂ and CO₂; Fischer Tropsch process to produce JP-5, F-76

Synthetic Hydrocarbon Fuels



Approach: Synthesis of hydrocarbon fuels using CO_2 and H_2 and electricity



100 mg/L of $[\text{CO}_2]_{\text{T}}$ in seawater vs. 0.7 mg/L $[\text{CO}_2]_{\text{T}}$ in air

Down-select Technologies to Convert Carbon Dioxide & Sea Water to Aviation Fuel



Enhancement of Fuel Energy by High Energy Density Nanoparticulate Additives

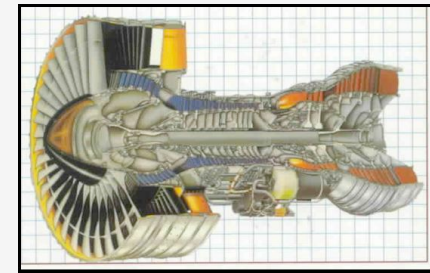
An Intermediate Solution

- **Provide greater enthalpy** of fuels than currently available carbon based sources
- Develop **highly energetic nanoparticles as additives** to enhance energy density of diesel for gas turbine engines

Research Challenges



- **Develop energetic nano-particle fuel additives for gas turbine engines.**
- **Enhance fuel combustion with catalysts.**
- **Surfactant coating for nanoparticle stability.**
- **Evaluation of combustion efficiency, acoustic signatures and coking**
- **Emission chemistry related to environmental and system impact**





Non Renewables



Energy: Coal Production

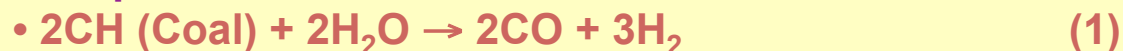
Coal Production figures for year 2002
(x 10⁶ tons)

Rank	Country	Amount
#1	China	1,956
#2	United States	1,008
#3	India	403
#4	Australia	365
#5	Russia	280

Liquid Fuel From Coal



- **Basic Equations:**



- (Fischer - Tropsch process)

- 24 lbs of coal produces 1 gal of liquid fuel
- US annual consumption 7-9 B bbl of fuel/yr

$$\begin{array}{ll} 8 \text{ B bbl} \times 42 \text{ gal/bbl} & = 3.4 \times 10^{11} \text{ gal of fuel} \\ \times 24 \text{ lb of coal/gal} & = 4 \times 10^9 \text{ tons of coal} \end{array}$$

- US mines 10^9 tons of coal/yr (~ 6% for export)
To meet national needs: 4 x annual coal production
- **Issues:** (1) disposal of solid waste from coal
(2) excess production of CO_2
(3) requires water

Energy Information Administration (2005)



Abundance of Frozen Clean Energy from the Sea

(Methane Hydrates)

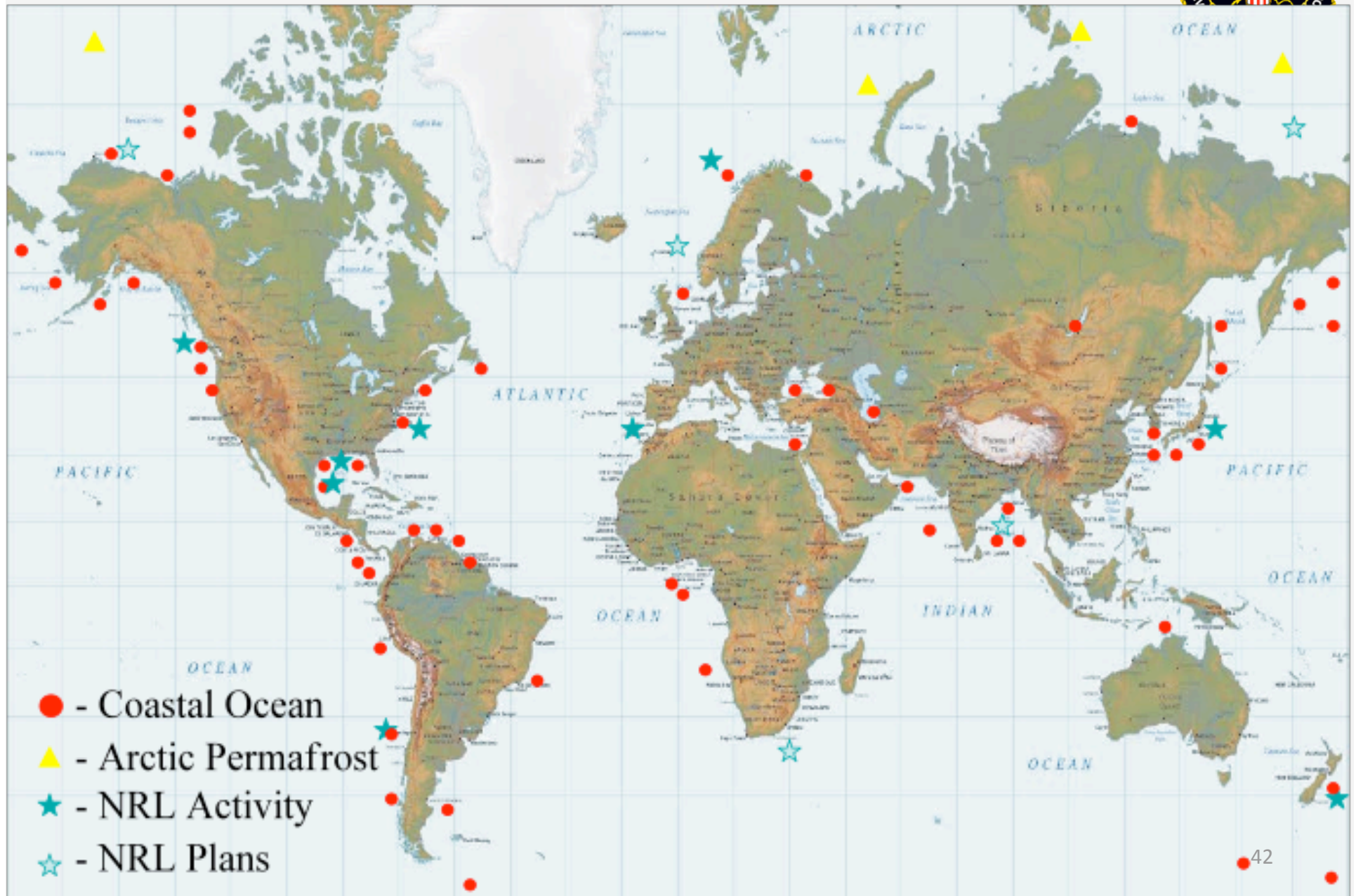


Volume of Gas Hydrate



One cubic meter of gas hydrate yields 164 m³ of gas and 0.8 m³ of water at STP

World Methane Hydrate Distribution





Estimated Hydrate Concentrations

National/Regional Estimates of the Amount of Gas Within Hydrates

(cubic feet)

United States

317,700 x 10¹²

Blake Ridge, USA

635 x 10¹²

2471 x 10¹²

2844 x 10¹²

2012 x 10¹²

1331 x 10¹²

North Slope, Alaska

590 x 10¹²

Nankai Trough

1765 x 10¹²

Andaman Sea, India

4307 x 10¹²

Collett 1995

Dillon & others 1993

Dickens & others 1997*

Holbrook & others 1996*

Collett 2000*

Collett 2000

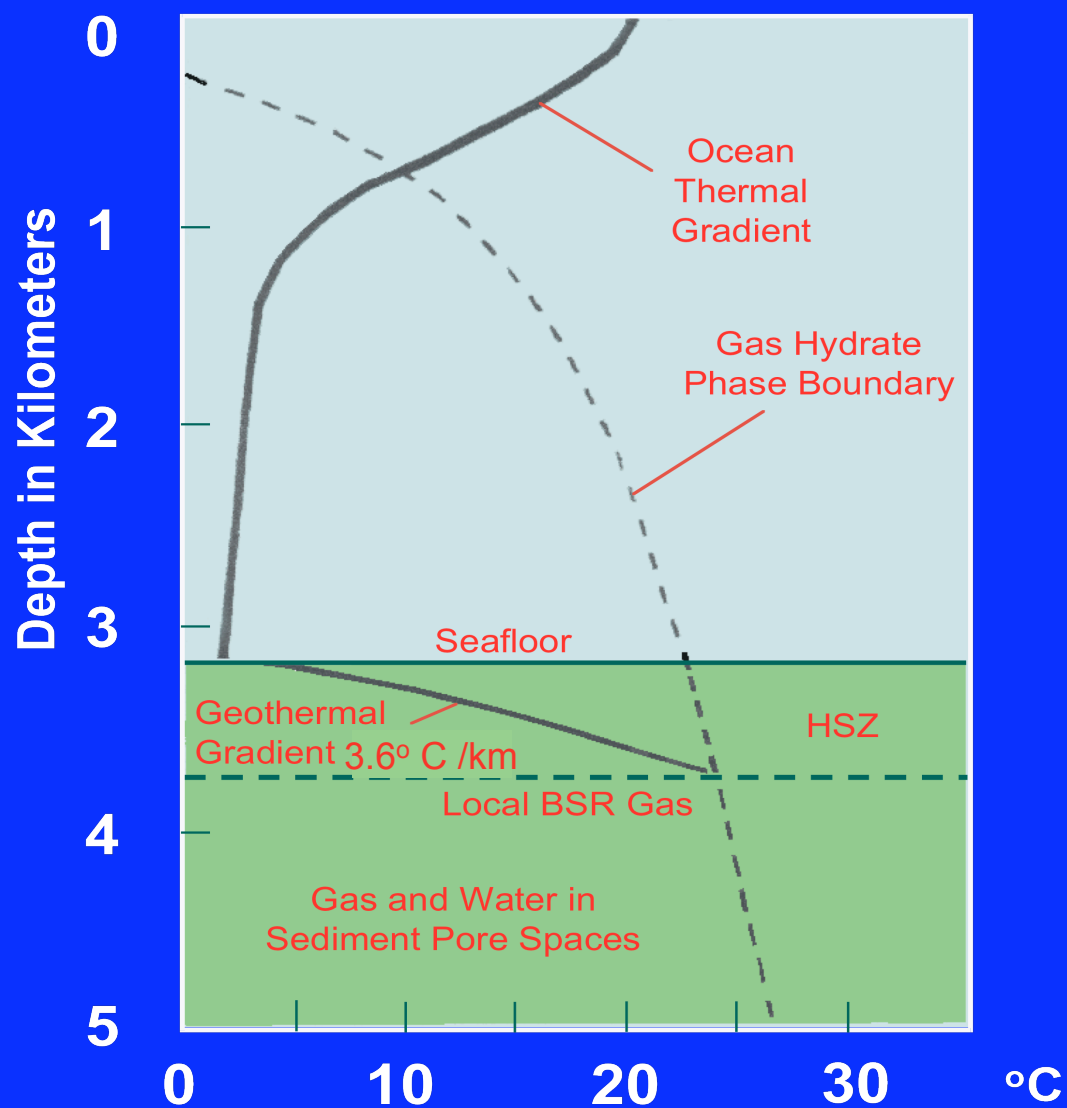
Collett 1997

MITI/JNOC 1998

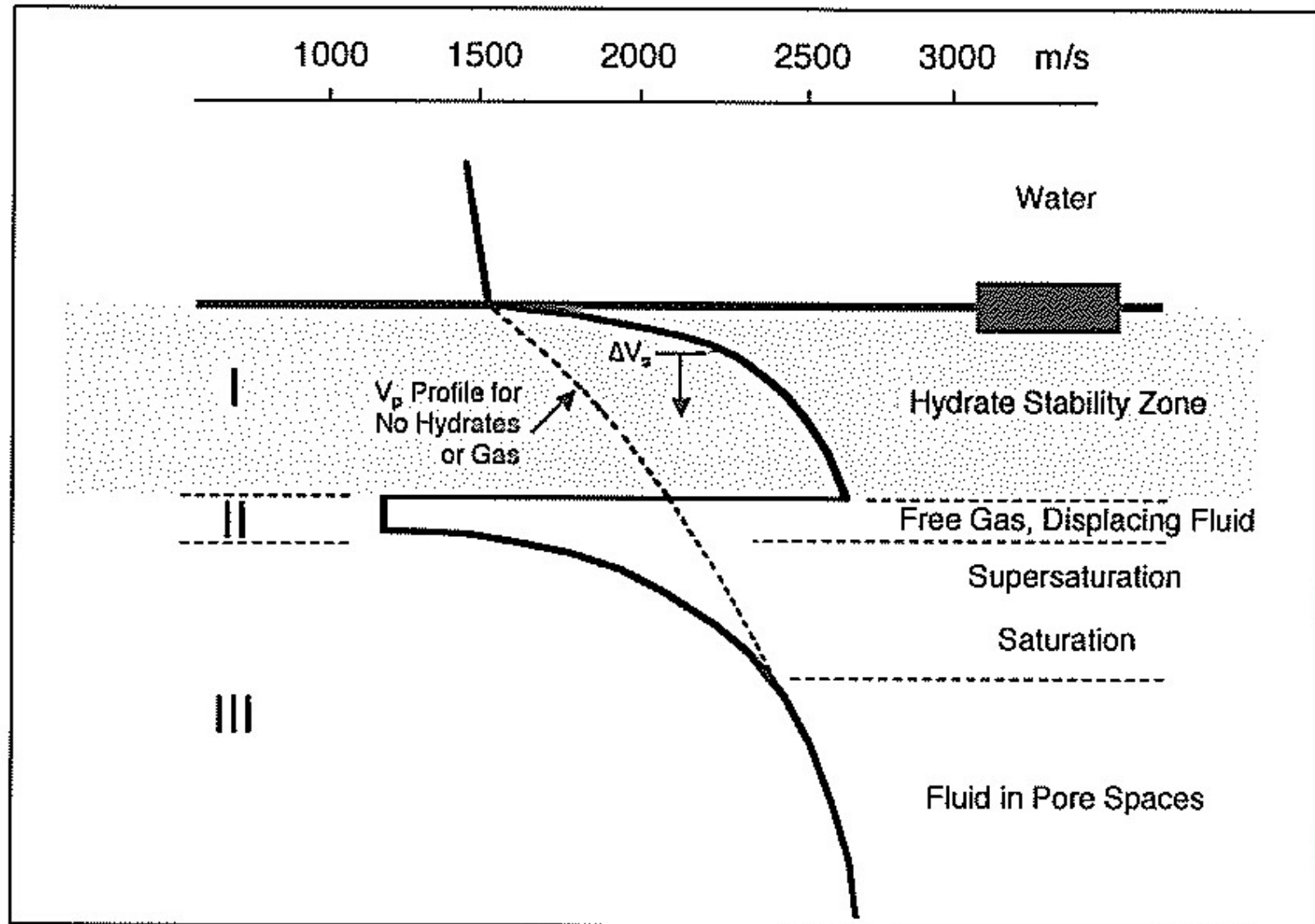
ONGC 1997



Methane Hydrate Stability Diagram



Geoacoustic Profile

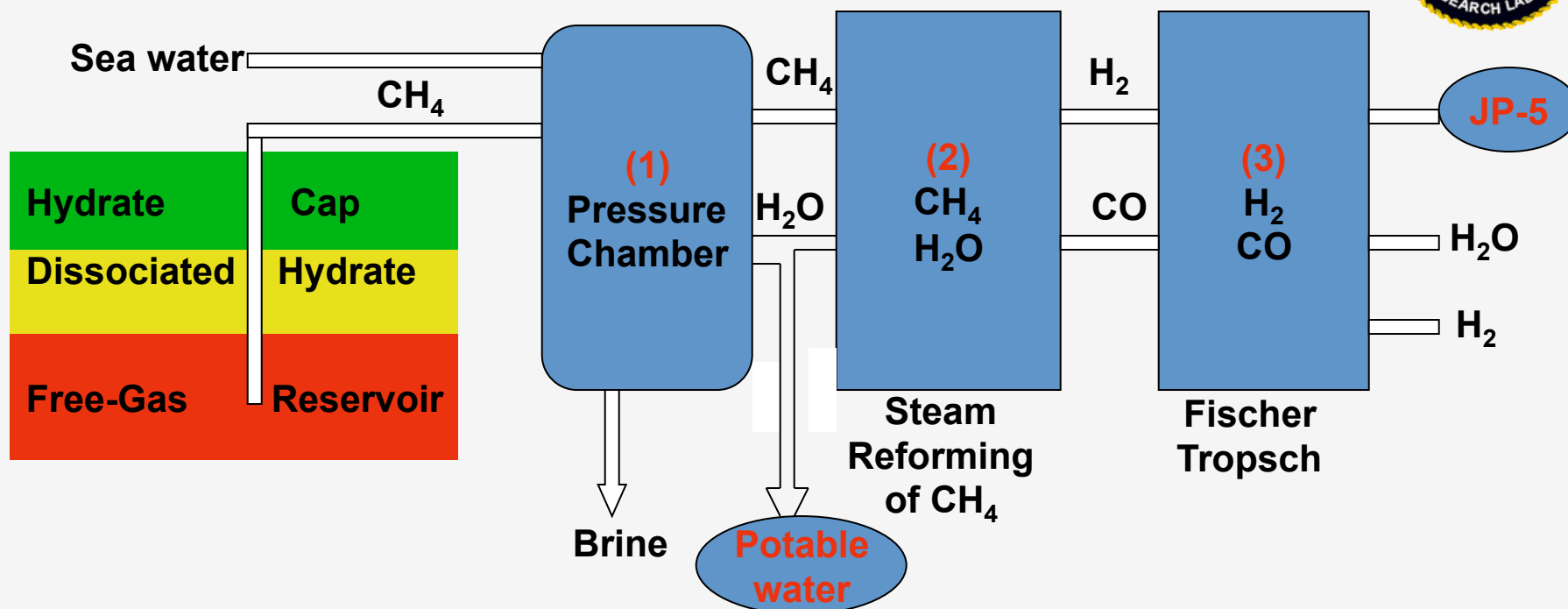


Studies of Gas Hydrates in Ocean Sediments



- **Seismic**
Structure of sediments and phase boundaries (BSR) from seismic reflections
- **Geochemistry**
Geochemical parameters (sulfates, sulfides, chlorine, water, hydrate history, etc.)
- **Electromagnetics**
Resistivity fluctuation in sediments
- **Heat Flow**
Temperature and thermal conductivity profile, effects of hydrate dissociation on fluid flux
- **Micro- and Macro-biology**
Role of bacteria and microbes on creation and dissociation of hydrates
- **Drilling**
Establish ground truth against other measurements

Methane and Seawater from the Sea to JP-5 and Potable Water



pressure

- 1) $\text{CH}_4 + \text{H}_2\text{O} \xrightleftharpoons{\text{pressure}} \text{Clathrate (hydrate)}$
- 2) $13\text{CH}_4 + 13\text{H}_2\text{O} + \text{Energy} = 39\text{H}_2 + 13\text{CO}$
- 3) $39\text{H}_2 + 13\text{CO} = \text{C}_{13}\text{H}_{28} \text{ (JP-5)} + 13\text{H}_2\text{O} + 12\text{H}_2 + \text{Energy}$

Energy for the 21st Century

“The crisis facing our civilization would make the World War II years look like good times”

Thank you

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